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Reply to comment by P. Passalacqua and E. Foufoula-Georgiou on "Objective extraction of channel heads from high-resolution topographic data"

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1. Introduction

We would like to thank *Passalacqua and Foufoula-Georgiou* [2015.] for their comment on our work and their clarification of the GeoNet methodology [*Passalacqua et al*., 2010a]. The main concern that they express in their comment is on the use of user-defined parameters in our testing of the GeoNet method [*Clubb et al*., 2014]. In particular, they argue that the contributing area parameter, which we set at a constant value across each field site of 3000 m^2, should be changed for each field site according to either field-based knowledge of channel head locations, or based on scaling relationships from slope-area plots. In our reply, we aim to clarify our motivation for keeping a constant contributing area parameter for each field site, along with discussing the alternative strategies for channel identification and their applicability in different landscapes.

We note that in our paper, we stated that GeoNet contained five user-defined parameters, rather than three as stated by *Passalacqua and Foufoula-Georgiou* [2015]. The authors of GeoNet admirably made their software open to the community and this software allows the user to modify five parameters. We thus assumed, like *Pelletier* [2013, p. 2] previously, that GeoNet requires five parameters. *Passalacqua and Foufoula-Georgiou* [2015] have clarified that only three parameters should be modified and explain the meaning of each parameter. We thank them for this contribution and think it will be very helpful to researchers aiming to identify channel heads. *Passalacqua and Foufoula-Georgiou* [2015] disagree with our statement "none (of the previous methods) have been tested against a robust field data set of mapped channel heads across multiple landscapes" [*Clubb et al*., 2014, p. 1]. They state that the GeoNet methodology has been tested on three different landscapes: Skunk Creek, CA [*Passalacqua et al*., 2010a]; Rio Cordon, Italy [*Passalacqua et al*., 2010b]; and Le Sueur River Basin, MN [*Passalacqua et al*., 2012]. We note that the GeoNet algorithm was tested in only one catchment in Skunk Creek, and against 16 mapped channel heads at the Rio Cordon basin. The analysis of the Le Sueur River Basin is based on comparing geometric and Laplacian curvature [*Passalacqua et al*., 2012], and does not involve testing the method against any field-mapped channel heads. However, our study tested each of the channel head extraction methods against a total of 167 mapped channel heads from four different landscapes: the Feather River, CA; Mid Bailey Run, OH; Indian Creek, OH; and the Piedmont, VA [*Clubb et al*., 2014]. Therefore, our statement quoted above simply referred to the fact that our study has tested each of the methods on a much larger data set than was previously available.

2. Use of the Contributing Area Parameter in GeoNet

Passalacqua and Foufoula-Georgiou [2015] provide a detailed description of the contributing area parameter used in the GeoNet method in their comment, and state that "this skeleton thinning parameter is not used to impose a channel initiation area". They argue that this value should be set for each field site, and should be smaller than the minimum channel initiation area. However, the objective of our study was to test each method of channel head extraction assuming that the location of the channel heads in the field was not known, and therefore, user-defined parameters were kept constant across all field sites. For example, when testing the contour curvature method of *Pelletier* [2013], we kept a constant curvature threshold of 0.1 m^{-1} across each of the sites. When testing the DrEICH method [*Clubb et al*., 2014], we kept a constant number of linked pixels used to identify valleys, set at 10 m. The other parameter used in the DrEICH method is the *m/n* ratio, which is computed automatically using the independent statistical routines of *Mudd et al*. [2014], in the same way that the quantile-quantile curvature threshold within GeoNet is computed automatically [*Passalacqua et al*., 2010a]. Therefore, we kept the contributing area parameter within GeoNet constant as a conscious choice, to ensure that parameters were not changed based on field-mapped channel heads. We agree that the results of the GeoNet method may be improved by optimizing the contributing area parameter based on the knowledge of field-mapped channel heads. However, the DrEICH method and *Pelletier*'s [2013] method may also be optimized by changing their user-defined parameters.

Passalacqua and Foufoula-Georgiou [2015] state that changing the contributing area parameter thins the channel network skeleton but does not affect the channel heads. In the Bald Rock Basin field site, they state that after changing the contributing area parameter "no significant difference is observed in the detected channel heads except that channel head locations have moved upstream" [*Passalacqua and Foufoula-Georgiou*, 2015, p. 9]. Figures 1–3 in their comment, along with the sensitivity analysis in *Clubb et al*. [2014], clearly show that the value of this parameter has a fundamental impact on the structure of the network. Their Figure 2 in particular shows that changing the contributing area parameter for the Bald Rock Basin site moved the channel head locations upstream, which we argue is a significant difference in the channel head locations. A key measure of success of a channel head prediction algorithm is identifying the predicted channel heads as either "true positives," "false positives," or "false negatives" [*Orlandini et al*., 2011]. The figures shown in *Passalacqua and Foufoula-Georgiou* [2015] demonstrate that varying the contributing area parameter significantly changes the number of tributaries that the GeoNet method predicts. This is also evident in the sensitivity analysis performed by *Clubb et al*. [2014], and leads to variability in the success of the algorithm between different field sites. Therefore, we suggest that the value of the contributing area parameter does affect the location of the channel heads and the resulting drainage network.

The location of channel heads, and therefore, drainage density, may exhibit strong spatial variability in a range of landscape characteristics, such as lithology [*Oguchi*, 1997], vegetation cover [*Istanbulluoglu and Bras*, 2005], and geomorphic process [*Tucker and Bras*, 1998]. If no information regarding the location of field-mapped channel heads is available, *Passalacqua and Foufoula-Georgiou* [2015] suggest that slope-area plots may be used to suggest a minimum channel initiation area. However, our assessment of slope-area plots as a method of predicting channel head locations [*Clubb et al*., 2014, Figure 6] shows that it is extremely difficult to constrain a minimum channel initiation area from a slope-area plot due to noise within the data. Slope-area plots for each of the field sites analyzed by *Clubb et al*. [2014] show no clear relationship between the location of field-mapped channel heads and any scaling breaks in the slope-area plot, which were traditionally used to identify channel head locations [*Montgomery and Dietrich*, 1988]. *Passalacqua and Foufoula-Georgiou* [2014] also suggest that the drainage area of channel heads may be estimated by visual inspection of LiDAR. However, in our study, we found that the location of the field-mapped channel head does not always correspond with apparent convergence from a LiDAR-derived hillshade. Therefore, our analysis ensured that the user-defined parameters of each model were kept constant across the field sites to test their success if no prior data on channel head locations were available.

3. Applicability of the Different Methods

Passalacqua and Foufoula-Georgiou [2015] raise an important point in their comment regarding the applicability of the various methods of channel head extraction in different landscapes. They state that "Many landscapes are human impacted with artificial roads and channels that do not adhere to erosion transport laws that imprint themselves in the standard slope-area relationships and the approach followed in *Clubb et al*. [2014]". We agree that different methods of extracting channel heads will be more appropriate depending on both the landscape and the aim of the study in question. We emphasised the differences in approach between the *Pelletier* [2013] and the GeoNet methods with respect to the DrEICH method throughout our paper, by separating the two different approaches into "Geometric techniques" and "Process-based techniques."

The presence of roads and other artificial features is an important challenge in automatic feature extraction. The GeoNet method can be used in this type of landscape through the application of Laplacian curvature rather than geometric curvature, as described in *Passalacqua et al*. [2012], and may be more accurate than the curvature method of *Pelletier* [2013] in human-impacted landscapes. In some cases, the presence of roads does influence the flow routing from the channel heads predicted by the DrEICH algorithm, although it does not affect the selection of the channel head itself from the longitudinal profiles. This may be improved upon by alternative methods of flow routing, such as multidirectional flow routing, which can be implemented following the prediction of the channel heads. Although we did not test the DrEICH algorithm on a heavily engineered landscape, we intend to test it in many more areas in future work.

Studies which are interested in identifying convergent topography may be more suited to using a geometric technique, such as GeoNet or the curvature method of *Pelletier* [2013]. However, this is different from identifying the topographic signature of fluvial incision, which the DrEICH algorithm can pick out using transformed longitudinal profiles of rivers and hillslopes. Previously, the only process-based method of identifying this transition involved looking for scaling breaks in slope-area plots, which we showed to be unsuccessful in our study [*Clubb et al*., 2014, Figures 6 and 7]. Therefore, the DrEICH algorithm provides a novel process-based method of predicting channel head locations which is proven to be accurate within tens of meters across multiple landscapes.

4. Software Availability

The code used in the DrEICH methodology is open source and can be downloaded from http://csdms.colorado.edu/wiki/Model:DrEICH_algorithm. The channel head data used in *Clubb et al*. [2014] are also available free to download from the Edinburgh DataShare repository: http://datashare.is.ed.ac.uk/handle/10283/524.

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